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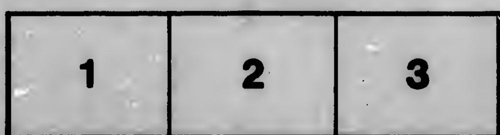
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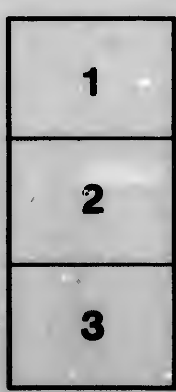
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REPORT

TO THE

SECRETARY OF THE NAVY

ON

RECENT IMPROVEMENTS IN ASTRONOMICAL INSTRUMENTS.

By SIMON NEWCOMB,
PROFESSOR, U. S. NAVY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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48TH CONGRESS, 1st Session. } SENATE. { Ex. Doc. No. 96.

MESSAGE

FROM THE

PRESIDENT OF THE UNITED STATES,

TRANSMITTING

A communication from the Secretary of the Navy, including a report on recent improvements in astronomical instruments.

FEBRUARY 12, 1884.—Read and referred to the Committee on Naval Affairs and ordered to be printed.

To the Senate:

I transmit a communication, under date of the 8th instant, addressed to me by the Secretary of the Navy, covering a report of Prof. Simon Newcomb, United States Navy, on the subject of recent improvements in astronomical observatories, instruments and methods of observation, as noted during his visit to the principal observatories of Europe, in the year 1883, made in pursuance of orders of the Navy Department.

The request of the Secretary is commended to the consideration of Congress.

CHESTER A. ARTHUR.

EXECUTIVE MANSION,
February 11, 1884.

NAVY DEPARTMENT,
Washington, February 8, 1884.

SIR: I have the honor to transmit the report of Prof. Simon Newcomb, United States Navy, on recent improvements in astronomical observatories, instruments and methods of observation, as noted during a visit to the principal observatories of Europe in the spring and summer of 1883, made in pursuance of orders of this Department. The report is considered of sufficient importance to be laid before Congress and printed.

Very respectfully, your obedient servant,

WM. E. CHANDLER,
Secretary of the Navy.

The PRESIDENT.

NAUTICAL ALMANAC OFFICE, NAVY DEPARTMENT,
Washington, D. C., January 29, 1884.

SIR: In pursuance of orders from the Department I visited certain of the leading observatories on the continent of Europe during the past year for the purpose of collecting information respecting the most recent improvements in astronomical instruments and methods of observation. I now have the honor to submit the following report upon the knowledge thus gained. The heads of this report are not arranged with respect to the different establishments visited, but with respect to the different kinds of instruments, all that relates to each instrument being collected together, even when the material was gathered at various places.

The establishments visited from which valuable information was gathered, were the observatories of Paris, Neuchatel, Geneva, Vienna, Berlin, Potsdam, Leyden, and Strassburg, and the workshop of the Messrs. Repsold at Hamburg. At the latter place I enjoyed the opportunity of meeting Director Struve, of the Pulkowa Observatory, and of discussing with him and the Repsolds the plans of the great 30-inch refractor, the objective of which had just been completed by the Messrs. Clark.

It is both a duty and a pleasure to acknowledge the very cordial reception I met from the directors and astronomers of the various observatories, and the facilities which were everywhere afforded me for the execution of the mission with which I was charged. In every case the fullest liberty was accorded me to make as critical an examination of every point as circumstances permitted.

In this report it is not practicable to present that exhaustive discussion of the subject of recent instruments which might have been expected, for the reason that within the limited time at my disposal it was not possible to prepare the detailed drawings and make the tests which would have been necessary for that purpose. I shall therefore confine my report to such special points as appear most important to persons who may intend to found new observatories, or to design or purchase new astronomical instruments.

THE GREAT VIENNA TELESCOPE.

Among the instruments which I have examined, that to which most interest now attaches is the great telescope recently completed for the Imperial Observatory at Vienna, by Howard Grubb, esq., of Dublin. It is the largest refracting telescope in actual use at the present time, being of one inch greater aperture than that of the Naval Observatory at Washington. The contract was made with Mr. Grubb in 1875, but, owing to difficulties in procuring glass disks of the necessary size and purity, it was not completed until 1881. Further delay occurred in mounting, so that it was barely ready for active work at the time of my visit in April last. I made as careful and critical an examination of its working as was possible during the unfavorable weather which prevailed at that time at Vienna. My examination was principally in the nature of a comparison of its working with that of the Washington telescope.

General style of mounting.—In its main features the telescope is mounted on the same fundamental plan as that at Washington, each being on the German plan, with the German system of counterpoises and with a steel tube. In both, the rapid motion in declination is by means of a rope attached to the two ends of the tube; that in right ascension by a system of wheel-work. In both, the clock-work is in the pier below the instrument. The leading points of difference are, that the mounting of the Vienna telescope is much larger, stronger, and heavier in all its parts, that the appliances for using it are more elaborate and numerous, and that an elaborate system of friction rollers in declination is provided, while the Washington telescope has none. A more convenient system of illuminating the field and the divisions on the several circles has also been introduced. As a piece of mechanical engineering it reflects great credit upon its designer and constructor.

Ease of motion.—In moving the Vienna telescope one is at first struck with the fact that mere weight is a serious drawback in the management of such an instrument, but, when the motion is once commenced, the movement in right ascension is almost as easy as in the Washington telescope. It is, however, very different in declination. For reasons which neither Dr. Weiss nor myself was able to perceive, the friction rollers seemed to be of little benefit in easing the motion in declination, which was much more difficult than in the Washington telescope, and, in fact, quite a tax upon the strength of the observer at the eye-piece.

The quick motion for setting in right ascension is made below the end of the polar axis by turning a steel steering-wheel. This appliance is in every way inferior to the system at Washington, where the same motion is effected by an endless rope hung over a grooved wheel which the observer pulls hand over hand. By this arrangement the observer at the Washington telescope can make the required motion, with his eyes fixed upon the telescope or upon the vernier, as he may desire, and without giving any thought to the motion of the hands. But the handles of the steel wheel are much less convenient to take hold of than a rope; and if the motion is at all rapid the operator cannot turn his eyes to the moving telescope without danger of his knuckles being struck by the steel handles as he attempts to take hold of them without looking. The necessity for care in this respect makes the motion hesitating and laborious, at least to one unaccustomed to it.

The clock motion.—On the system of the Messrs. Clark, applied in the Washington telescope, the screw which turns the sector does not take hold of the circumference of the latter directly, but gears into a complete worm-wheel, around the axis of which is wrapped a pair of brass or steel bands which also enwrap the arc of the sector. By this arrangement the toothed wheel makes a nearly complete revolution while the sector is moving through its arc, and the effect of the small unavoidable irregularities in the working of the screw is diminished in the ratio of the arc of the sector to the circumference of the wheel. Whatever advantages this arrangement may have in small instruments, I think that in large ones they are more than counterbalanced by the irregularities arising from the elasticity of the band, combined with the variations of friction, and the action of wind and other forces operating to vary the uniform motion of the telescope. Owing to this elasticity, the effect of the wind or of any slight pressure by the observer on the eye-piece is many times greater in the Washington than in the Vienna instrument. But it did not appear to me that the firmness of the connection in the latter instrument between the support of the turning screw and the tube of the telescope was as great as was expected by those who lay stress on large and stable mountings. I found that by a simple pressure of the thumb-nail upon the tube of the Vienna telescope the pointing in right ascension could be changed by several seconds so as to throw an object entirely away from the wire.

The main question is, however, the steadiness of motion when no pressure whatever is applied by the observer, and so far I have found no large telescope which is entirely satisfactory. The Vienna telescope was not supplied with a micrometer at the time of my examination, so that I could not test its motion as thoroughly as I wished to; but by bringing the planet Uranus in the edge of the field I found that when the clock was going there was a constant irregular movement in right ascension, the amount of which I estimated as between one and two seconds of arc. This movement had no regular period, and therefore did not seem to be connected with any defect in the figure or motion of the screw. Its irregular period, if I may use the term, varied from the smallest appreciable amount to two or three seconds of time. Its most probable cause seemed to be the variable friction of the motion in right ascension and especially of the friction rollers by which the polar axis is supported at its lower end. A similar irregularity is noticeable in the Washington telescope, but when the conditions are favorable it is less than that noticed at Vienna. On the other hand, the effect of wind is much greater in the case of the Washington telescope.

Arrangement of sector.—In Mr. Grubb's large telescope, an attempt is made to give greater stability to the screw by having the ends of its axis to fit into firm supports in the massive base of the telescope, thus rendering it incapable of any motion except that of turning. The screw cannot therefore be unlocked from the sector as in the instruments by other makers. When the sector reaches the end of its motion, it has to be turned back by giving a rapid backward motion to the screw itself, for which special apparatus is provided. From what I have already said, I am of opinion that this arrangement offers no advantage to compensate for the trouble which it causes the observer.

Slow motion.—The slow motion in right ascension in the Vienna telescope is endless, instead of being confined between narrow limits as that at Washington. This is a decided improvement, saving the observer much loss of time from the motion running out, which it is sure to do from time to time.

Illumination.—The apparatus for illuminating the field of the micrometer was not in perfect order at the time of my visit, so that I cannot report upon it in this connection. It is in its general character similar to the system adopted by the Messrs. Repsold, of which I shall speak hereafter. The illumination of the divisions of the setting circles leaves nothing to be desired.

Minor points.—In the preceding remarks, I have indicated what may be considered fundamental points affecting the use of the Vienna telescope. There are, however, a number of minor points, which are of almost equal importance, so far as the practical use of the telescope is concerned. As the instrument now stands, the drawback which struck me most was the absence of any rough setting either in right ascension or declination, and the impossibility of seeing, even approximately, the pointing in declination, except when the observer was at the eye-piece. This want, combined with the great force necessary to move the telescope in declination, makes its pointing a difficult and troublesome operation. The observer must first set the telescope by pure guess-work. He has then to mount to the eye-piece, wherever it may be, look into the microscope, and note the reading of the circle. He has then to withdraw his eye, and by considerable muscular exertion to make another guess, which he again tests by reading the circle. Thus the pointing is to be made by a series of trials which are so troublesome that I found the observers were in the habit of mounting to the top of the cylinder of the dome and finding the pointing in declination by moving the telescope around the horizon.

I remark, in this connection, that the Washington telescope has a coarse setting which the observer can read from any point below the telescope with the aid of an opera-glass. This setting is sufficiently accurate to bring any object whose position is known into the field of view of the finder, and near its center.

Objective.—The proper figuring of an objective so as to give the best possible image, is justly considered the most difficult task in the construction of a large telescope. Especial interest, therefore, attaches to Mr. Grubb's success with the objective. The atmospheric conditions during my visit were unfavorable to the finest tests, but I succeeded in making such examination as the circumstances admitted of on three evenings. On the first trial, the image was found to be defective, owing to a want of adjustment of the glass itself. This was corrected next day by Director Weiss. On the second trial I found a well-marked spherical aberration, which seemed, however, to be very regular from center to circumference. But there had been a fall of temperature and the dome had been opened only a short time; circumstances under which the Washington telescope always exhibited the same phenomena. On the third evening, the dome had been opened long enough to nearly equalize the internal and external temperatures. So far as I could judge the character of the image was perfect, there being no appearance of those rings of different focal length, which are so often found in large objectives. As I had not used a large telescope for some eight years, I could not feel that my judgment was of the most critical kind, but I am persuaded that if any defects exist, they are so minute as not to interfere in any important degree with the finest performance of the instrument.

The color correction is less than in the Washington telescope. The result is that the blue areole around brilliant objects is much less striking.

THE GREAT DOMES AT PARIS AND VIENNA.

The proper performance of a large telescope is so much affected by the character of the dome in which it is placed, that the latter may be regarded as of equal importance with the mounting of the telescope. All my experience, however, leads me to the conclusion that there is no decided superiority in any special form of dome, but that the principal difference in the working arises from the quality of the workmanship. In choosing among a number of proposed forms we can only say that that which is best constructed is the best.

The Vienna dome was constructed by Mr. Grubb. It is built of iron, is 45 feet in external diameter, and weighs fifteen tons. Its working leaves nothing to be desired, except that its great weight renders its motion somewhat cumbrous. By moving it a short distance it appeared that one man could turn it in eight minutes. Mr. Grubb says that when first mounted a weight of seven pounds on the rope was sufficient to start it. I did not test this by actual trial, but cannot resist the conclusion that much more than seven pounds is now required.

The drum of the dome is of thick massive brick-work. I cannot but regard this sort of base as objectionable, even when pierced with numerous openings, as in the present case, owing to the difficulty of securing equable temperatures inside and outside.

Heretofore three methods of supporting a turning dome have been proposed:

I. On wheels, fixed either to the dome or to the base on which the dome rolls.

II. On a system of rollers connected by a live ring.

III. On cannon balls.

I conceive that the choice should lie between the last two. The cannon-ball system works the best of all so far as ease of motion is concerned; its drawback is the difficulty of keeping the balls at anything like equal distances apart. The system of rollers in a live ring was invented by Mr. Grubb, and is employed at Washington as well as at Vienna. It has the advantage of always working well, but is more troublesome in construction and requires more force than cannon balls.

To these three systems the French astronomers propose, in their new great dome, to add a fourth, by floating the dome in an annular trough forming the top of the drum. The base of the dome will then be a floating annular caisson. It would be hazardous to predict in advance how this ingenious plan will work. It will certainly have the advantage that a slow motion can be given with less expenditure of power than on any other system; but if the motion is at all rapid I am inclined to suspect that the friction of the fluid will be equal to that of the rollers on the other system. The difficulty which I should principally fear is the leaking of the caisson. The freezing of the water will be avoided by impregnating it with chloride of magnesium. It is intended to construct a dome on this principle 20 meters in diameter for the great refracting telescope now being constructed. It is feared, however, that the practical completion of the work will be long postponed, owing to the necessity of finding a better foundation for the structure than is now afforded by the grounds of the observatory.

THE GREAT RUSSIAN TELESCOPE.

In 1879 Privy Counselor Otto Von Struve, director of the Pulkowa Observatory, visited this country and contracted with the Messrs. Clark for the construction of an objective 30 inches in aperture. It was completed and delivered during the year 1882. The mounting is now being completed by the Messrs. Repsold, of Hamburg. Although still unfinished, I was desirous of gaining all the information possible respecting its construction, and therefore visited Hamburg for the purpose of examining its parts. The following are some essential points in the structure:

The most striking feature of the instrument will be the absence of friction rollers from the declination axis. With so large an instrument the friction on the declination axis will be too great to admit of the telescope being conveniently turned either by hand or by a rope attached to the two ends, as at Washington and Vienna. The quick motion in declination will be given by a system of cog-wheels turned by an axis passing through the polar axis of the instrument and coincident with it. This axis will be turned by a crank at the lower end, or by the observer taking hold of the circumference of a wheel, at choice. Although the turning of the crank is a more convenient motion for the purpose than that of taking hold of the handles of a steering-wheel, I do not consider it so convenient as pulling a rope. This system of wheel-work will also be connected with the axis of a crank at the eye-piece which the observer can take hold of and turn without leaving the eye-end of the telescope. A second crank will be furnished for the motion in right ascension.

Instead of using a sector for the clock motion the screw will gear into a complete wheel about two meters in diameter. The trouble of having to turn the sector back will thus be avoided. The illumination of the finding circles and the arrangements for reading them will, in their results, be similar to those used on other large telescopes; that is, the arrangement will be such that the observer can read either circle from the eye-piece. The system of illuminating the field wires, micrometer, position circle, &c., though extensively employed in Europe, is so little known in this country that attention should be called to it. The side of the telescope at a convenient distance above the eye-end is pierced by an opening on the opposite side from the declination axis. Through this opening passes a conical tube parallel to the declination axis. At the outer end of this tube is a reflector inclined at an angle of 45 degrees to the axis of the cone, but turning on an axis coincident with that of the cone. The illuminating lamp shines upon this reflector and turns upon the same axis with it. It is also hung upon gimbals so as to turn upon a secondary axis coincident with the axis of its own line of light. The result of this arrangement is that the lamp always hangs vertically, whatever the position of the telescope, and that the horizontal beam of rays thrown from it always strikes the mirror at an angle of 45 degrees in such a way as to throw the light directly through the conical tube and into the telescope.

The slightly divergent beam which fills the cone is divided into two or three concentric portions. One of these is reflected upward to the object-glass, and by reflection from the glass itself illuminates the field of view. Another portion shines upon four whitened surfaces around the sides of the micrometer, by which both sets of wires are illuminated. The portion of light which is not needed for this purpose is so arranged as to illuminate the two verniers of the position circle and the heads of the micrometer. So far as I could judge, the working of this plan leaves nothing to be desired in the way of convenience to the observer.

Worthy of special attention are the eye-piece micrometers now made by the Messrs. Repsold. They include every contrivance necessary for rapid and convenient use.

Support of the polar axis.—Another important feature, which has been applied by the Repsolds in their other large instruments, is the method of supporting the polar axis. This axis has to bear a large part of the instrument, counterpoises included. As ordinarily made, it is necessarily subject to an end thrust equal, in our latitude, to two-thirds the weight of the instrument. How to support this thrust without interfering with the ease and freedom of motion has been one of the difficult problems in mounting a telescope. In the Repsold instrument the thrust is nearly avoided by supporting the polar axis upon a vertical friction-wheel under the center of gravity of the entire instrument. Counterpoises can be placed at the lower end of the axis so as to balance the instrument upon this wheel. So far as I can judge, this plan leaves nothing to be desired.

PRACTICAL CONCLUSIONS.

I have been led by the examination above described, combined with some experience in the use of the Washington telescope, to some conclusions respecting the most appropriate features in the mounting of an instrument of the larger size. They may be here enumerated for the consideration of those engaged in constructions of this kind.

I. I think that in order to secure the necessary stiffness with the least weight the axes should be hollow. The material can then be made comparatively thin. It is true that the larger the axis the greater the friction. But the mass of metal in the interior of the axis contributes so little to its stiffness that the external diameter will have to be increased very little to secure the same stiffness with the hollow axis as with the solid one.

II. It is not worth while to supply the declination axis with friction rollers unless experiment and research shall show that they can be made more effective than they appear to be in the Vienna instrument.

III. The best quick motion in right ascension is that adopted in the Washington telescope, where the observer pulls an endless rope hand over hand, and can lock and unlock the gearing which connects the turning-wheel with the telescope at pleasure.

IV. If, as is possible, the quick motion in declination, by means of a loose rope attached to the two ends of the telescope, requires too strong a pull, the best method of giving this motion is through a gearing turned by an axis passing centrally through the polar axis on the Repsold plan. But it is preferable to have this motion made by turning a crank or pulling a rope rather than by taking hold of a wheel.

V. Coarse divided wheels should be supplied, so that the observer while turning the instrument can constantly see its approximate pointing. It is better if this coarse reading can be made with the naked eye, as is the case in the right ascension movement of the Washington telescope. The declination circle being further from the observer, it has to be read with an opera-glass if more than a coarse fraction of a degree is required. By such an arrangement the telescope can always be set by the quick motion so nearly that any object sought shall be in the field of view of the finder. In nine cases out of ten this will be all that is required in practical use. It should never be forgotten that in all quick motions it is very desirable that the observer shall be able to keep his eye upon the movements of the telescope itself in order to save him from any apprehension, even a groundless one, that something may be going wrong.

VI. The slow motion should if possible be endless. There is no difficulty in making it so in right ascension; though there may be in declination.

VII. When the instrument is so large that there is an interval of three feet or more between the center of the polar axis and the side of the tube, the screw which communicates the clock movement should be geared into a complete circle rather than into a sector. The use of the metal band to multiply the effective radius of the wheel offers no advantage in the case of large instruments to compensate for the disadvantage of want of stability arising from elasticity of the band and its fastenings.

VIII. In this connection should be considered the question of applyign the system of Aing, which consists in giving a clock-motion to the verniers of the right-ascension circle so that their position shall represent sidereal time. Every practical astronomer is familiar with the trouble in setting an ordinary equatorial, arising from the necessity of having to calculate the constantly varying hour angle of the object on which he points. With the Greenwich arrangement there is no such trouble. The clamping-wheel being once set to sidereal time, the observer has only to set the other one to the constant right ascension of the object. It is true that practical difficulty arises in the usual construction, owing to the fact that the vernier on the gear-wheel will from time to time be on every point of th circle. But this difficulty can, I think, be obviated by appropriate arrangements.

IX. A clock motion which can be kept up by water or other power is greatly preferable to any system which requires an assistant to wind up a weight.

X. The entire practicability of illuminating the divisions of the circles by a lamp and of reading these divisions from the eye-end of the telescope has been so completely demonstrated that all large instruments should be supplied with this arrangement. It can hardly be doubted that electric lights will hereafter take the place of lamps for this purpose.

XI. The system of illuminating wires, field, micrometer-head, &c., by a single lamp, which shall be vertical in all positions, has been so perfected by the Repsolds that it leaves nothing to be desired.

XII. The Washington plan of having the whole micrometer plate, including both fixed and movable wires, moved by a fine screw which has not necessarily a divided head, offers such a convenience in setting that it should always be adopted.

XIII. The old system of having a single finder on that side of the telescope which is opposite the declination axis becomes very inconvenient in a large instrument, owing to the necessity of setting the slit in the dome not only to the telescope but to the finder. The plan adopted in the Vienna telescope of having two finders, of which one shall be above and the other below the telescope when the latter is in the meridian, obviates this difficulty and should always be adopted.

REFLECTING TELESCOPES IN FRANCE.

It is well known to all who have given attention to this subject that the optical performance of great reflecting telescopes has never been proportional to their size, and that the mechanical difficulties of keeping a large reflector in proper figure in different positions have been apparently insurmountable. A plan of supporting a large mirror, devised by the Messrs. Henry, has been adopted in Paris, which it is hoped may obviate this difficulty. It consists, in principle, in supporting the mirror upon a mass of metal of a form similar to that of the mirror, the surface of which is ground to fit the lower surface of the mirror with accuracy when the latter is in proper shape. If the mirror rested directly in contact with this second surface no advantage would be gained, since the backing itself would bend as readily as the mirror. Therefore between the two is inserted a thin stratum of some elastic substance. M. Henry has found a sheet of fine flannel to give the best results. The effect of the sheet is to diminish the flexure of the mirror by a fraction depending upon its stiffness and upon the elasticity of the flannel. Theoretically it may be considered imperfect, because, in order to act, some stiffness is required in the mirror itself. A perfectly flexible mirror would bend just as much with the flannel as without it. But flexure of the mirror can, it appears to me, be reduced to quite a small fraction of its amount. Moreover, I see no insuperable objection to the superposition of two systems of the kind, the mirror resting upon a stiff disk which is itself supported upon a second one.

This plan has been entirely successful in the cases in which it has been applied, mirrors up to 12 inches in diameter showing not the slightest flexure when moved into all practical positions. Unfortunately it has not yet been tried with reflectors of a larger size.

THE EQUATORIAL COUDÉ.

By applying the simple method just described for mounting mirrors, an equatorial surpassing all others in convenience of use has been put into operation at the Paris Observatory. The plan of having a telescope of which the tube itself should be the polar axis, so that the eye-piece should constantly point towards the north pole, is quite familiar to astronomers. The plan heretofore proposed is this:

Below the object-glass, which in the northern hemisphere would point towards the south pole, is to be placed a reflector capable of turning round an axis at right angles to that of the telescope while the latter turns upon its own axis. The latter motion would the measure right ascension and the revolution of the mirror would be one-half the change of the declination. This plan is subject to the inconvenience that, in order to look near the south horizon, the mirror would have to be much elongated, while the view around the north pole would always be cut off by the intervention of the telescope itself.

In the equatorial coudé this difficulty is obviated by the use of a second reflector. The telescope, as its name indicates, is elbow-shaped. Its lower part consists of an arm at right angles to the axis. At the elbow is fixed a mirror, from which the light is reflected at an angle of 45 degrees. At the outer end of the arm is a second reflector, also at an angle of 45 degrees, and turning upon a central axis of this arm. By its motion, the field of view of the telescope will sweep over a belt of uniform width from the pole to the horizon, so that its position angle will correspond to declination. By turning the whole instrument on its axis the field of view will sweep through a zone of constant declination. The object-glass is in the arm between the two reflectors. The angle of reflection from each mirror is constantly 45 degrees.

The advantage of this construction is, that the observer does not have to follow the eye-piece of his telescope, but always sits in a fixed position in a comfortable room. All the motions and all the readings are made as he sits at the eye-piece. The amount of work of a certain class that can be done with the telescope is thus greatly increased. The form is, however, inadmissible in an instrument in which the highest optical power is aimed at, owing to the loss of light by the double reflection. In a large instrument, I should also fear injury to the images from the bending of the mirror, but no such effect shows itself, at least in any striking degree, in the Paris instrument, which is of about ten English inches aperture.

THE STRASSBURG MERIDIAN CIRCLE.

This instrument is commonly considered to embody the latest conceptions in astronomical mechanics. Its general design is founded on that adopted in the great meridian circle of the Harvard College Observatory which was constructed by Troughton and Simms, of London. The original design of the latter instrument is, it is understood, largely due to the late Professor Winlock. The most essential modification of the older plan is that the Y's and the reading microscopes, instead of being supported upon piers of stone, are borne by a massive metal foundation, the tops of the piers being below the level of the bottoms of the circles. The drawbacks arising from the unequal contraction and expansion of the stone piers, under the influence of variations of temperature, are thus almost entirely avoided, because the metallic supports rapidly assume the temperature of the surrounding air and of the instrument.

Every part of the instrument bears the impress of the thought and care devoted to its construction both by the makers (the Messrs. Repsold) and by Professor Winnecke, the director of the observatory. Even the form of the piers of masonry which support it and its collimators is highly original. The base of the principal pier is smaller than usual, and the amount of material in it is still further diminished by building it in the form of a Greek cross. The collimators are supported on cylindrical piers of the usual construction. Each of these three piers is protected from changes of temperature by having a hollow cylinder of brick built up around it from the ground. The thickness of the wall of this cylinder is that of one brick. To insure stability the different cylinders are connected together by brick arches, but these arches do not exert any pressure upon the interior piers supporting the instrument, which rests only on their foundation. A degree of stability is thus secured which I believe has never before been reached.

But this may be in great part due to the excellence of the foundation.

The observatory building rests upon a stratum of gravel so clean and pure that in case of a flood in the Rhine the water permeates through the gravel to the base of the piers. It might be supposed that water thus penetrating the foundation would produce an injurious effect upon the stability, but such is not found to be the case. The fact that gravel forms the best foundation for an astronomical instrument has long been understood by those who have given attention to the subject. But I do not know of any other case in which the saturation of the gravel with water has been experienced.

I may mention in this connection that a solid bed-rock might be even better than gravel were it covered with so deep a layer of soft earth that it would not be affected by daily or annual changes of temperature. Experience has, however, shown that for want of these conditions being fulfilled a solid rock forms a very unsafe foundation. An interesting example of this is afforded by the observatory at Neuchatel, which is erected at the base of the Jura Mountains. The annual change in the pointing of the meridian circle is so great that Dr. Hirsch has recently published an investigation of the subject, showing that the mountain undergoes an annual change to an extent which has never before been remarked.

In order to obtain an accurate estimate of the stability of the Strassburg instrument, I requested the acting director, Dr. Schur, to allow me to transcribe the instrumental corrections during as long a period as practicable. The following are the values of the three instrumental constants which depend on the deviation of the axis of rotation from a true east and west line. Column *i* gives the level correction; *n*, the distance of the line of collimation east of the pole; *m* the deviation of the same line at its point of intersection with the equator. Of these constants *n* is more accurately determined than either of the others, and its stability affords a test of the stability of the instrument both in level and azimuth.

	i.	*n*.	*m*.
1882.	*s*.	*s*.	*s*.
June 17	.00	+.03	−.03
July 3	−.02	−.02	−.02
10	−.03	+.06	−.11
14	....	+.01	....
15	....	+.11	....
17	+.01	+.03	−.01
20	+.06	+.06	+.06
27	.00	+.11	−.12

	i.	*n*.	*m*.
1882.	*s*.	*s*.	*s*.
Aug. 24	+.13	+.18	−.01
25	+.29	....	....
29	+.09	+.06	+.04
Sept. 1	+.06	+.18	−.11
2	+.01	.00	+.01
6	+.03	+.09	−.06
9	+.02	+.20	−.19
19	+.01	+.08	−.08
25	−.01	+.02	+.01
25	+.01	−.01	.00
Oct. 4	+.23	+.07	+.26
7	.00	+.05	−.05
13	+.08	−.05	+.18
17	+.08	−.04	+.17
19	.00	+.05	−.06
21	+.01	+.04	−.03
23	+.06	−.02	+.13
26	−.01	+.08	−.10
28	+.01	−.03	+.04
30	+.04	+.12	−.08
31	+.03	+.05	−.01
Nov. 1	+.05	+.05	+.03
1	+.01	+.01	.00
3	+.00	+.05	−.06
6	+.03	+.08	−.02

It will be seen that if we take the mean value of *n*, $0^s.05$, as a constant for the four months the average deviation of the observed values from this mean will be less than $0^s.05$. A portion of these deviations are due to errors of determination and the accidental deviations of a temporary character due to changes in the temperature of the different parts of the instrument, produced by the impacts of air currents.

The stability of the nadir point appeared much less satisfactory. This correction was not determined with sufficient regularity to admit of its changes being the subject of a positive calculation, and Dr. Schur expressed himself not entirely satisfied of the accuracy of the determinations. It seems scarcely possible that the polar pointing of the instrument could be so steady if the nadir point were subject to considerable changes.

The stone piers are terminated on top by horizontal faces, in which are set the two iron supports of the Y's and of the microscopes. The base of each is an iron frame 18 inches from east to west, by 24 inches from north to south, which is set on the top of the stone and held in place by being bedded in cement. Upon this sets the base of the microscope holder, which rests on three feet, and may be adjusted horizontally by screws. I should myself suppose that greater security against accidental change would have been secured if the top face of the frame had each been planed to fit the base of the holder instead of having the latter on feet, provided some side support were added to guard against any possible minute rocking motion.

The microscopes are carried on the external surface of a cylinder, which is cast in the same piece with the base last described.

The fulcrum on which rests each lever supporting the weights of the instrument at one end and the counterpoise at the other is itself supported upon the cylinder carrying the microscopes. This feature of the instrument has been objected to on the ground that the microscope carriers should not be subjected to so great a pressure, which may possibly be subject to vibratory changes as the instrument turns upon the friction rollers. Although it is quite possible that no actual evil results from this cause, it must yet be regarded as a not improbable source of danger to the steadiness of the microscope holders; I therefore consider that it would be better to adopt some other system of supporting the instrument; perhaps upon pillars passing centrally through the microscope holders and set in the pier below.

The arrangements for clamping the microscopes to the cylinder leave nothing to be desired, provided the former are once got into their proper position. But the task of setting a microscope after it is once disarranged is extremely laborious, and some additional mechanism for effecting this is desirable.

The accuracy with which the divisions on the circle are cut, and the adaptation of the microscope to their reading, are undoubtedly the greatest points of difficulty in the construction of a divided circle of the first order. I am convinced that much must yet be done to secure the best results in this respect. In the Strassburg circle, and in the other recent instruments of the Repsolds, the diameter of the circle is reduced to two feet. One great advantage is thus secured in that the circle and the microscope are less subject to injurious changes from currents of air of different temperatures. But a drawback is at the same time introduced from the fact that, as the diameter is diminished, any error of a given amount in the position of the division will produce a proportionally greater effect in reading off the angle. Hence, in order that no accuracy may be lost from this cause, the absolute error of the divisions, their sharpness, and the power of the microscopes, must all be increased in the same proportion that the diameter of the circle is diminished.

It does not appear to me that the eminent constructors of the instrument have succeeded in this. In order that I might reach a precise conclusion on this point, I asked permission at Strassburg to collect the data and to make the determination necessary for a rough comparison with the Washington circle.

First, as regards errors of division, I found that these errors had been determined for every 5 degrees. The best method of making a numerical estimate of the accidental errors of division seems to be to compare the error of each division with the mean of the errors of the two adjoining ones differing by 5 degrees. I examined the table of errors through a portion of the circle with the result that the mean error as thus determined is 0″.32, while the maximum is 0″.63. It will be interesting to compare this with the Washington circle.

On page 37 of the Washington Observations for 1865 is found a table of the errors of the two circles of the Washington instrument. Treating them in the same way, we find:

Washington, circle A: mean error, 0″.28; maximum, 0″.79.
Washington, circle B: mean error, 0″.21; maximum, 0″.31.
Strassburg circle: mean error, 0″.32; maximum, 0″.63.

It will be seen that in angular position the errors of the Strassburg circle are in general about the same as those of circle A of the Washington instrument, but are decidedly inferior to those of circle B, which is the one always used in astronomical observation. The diameter of the Washington circle is, however, about six-tenths greater than that of the Strassburg instrument, thus showing that in linear measure the general accuracy is the same in the Strassburg instrument and the Washington circle B.

I must, in justice to the Messrs. Repsold, call attention to the fact that this comparison refers only to the particular sets of division which are distant 5 degrees, and does not refer to the general excellence of the dividing. Both the Washington circles exhibit a most unfortunate periodic error within each space of 5 degrees, and another within each space of 30 minutes or perhaps one degree. In circle B the maximum amount of this periodic error is 0″.27, and in circle A, 0″.46. I am not aware that any such error exists in the Repsold circle. It is proper to remark that the methods of dividing the two instruments were entirely different. In the Washington instrument the original divisions were made to every 5 degrees, and the intermediate ones are all copies of the same small dividing arc used by Messrs. Pistor and Martins for finishing the divisions. On the other hand, the divisions of all the Repsold instruments are copies of a certain large divided circle made by the founders of the firm more than half a century ago. The copy is, however, modified to this extent: instead of each division being copied, the copy is a mean of each five consecutive divisions on the original circle. Supposing the copies to be absolutely perfect and the original circle to have remained unchanged, all the Repsold instruments should exhibit the same errors of division, but I am not aware whether the numbering on the different circles is made to correspond to the same divisions of the original circles, a proceeding which would be necessary to test the uniformity. In this connection I may remark that during my visit to the Repsold establishment they allowed me to examine the divisions on the original circle with the aid of a powerful micrometer microscope attached to it, and used in making a copy. So far as I could judge from a cursory examination there were no sensible accidental errors of division in the minute space over which my observations extended. If so, the errors of division in the copy must be mainly accidental, and perhaps due to elasticity in the mounting of the cutting tool combined with irregularity in the resistance it meets with in cutting the metal. Should the errors of division be wholly due to this cause, we could expect no correspondence between those on different instruments.

The microscopes are about two feet long, and their absolute power is, I think, somewhat less than in the Washington instrument. It did not appear to me, however, from examining the divisions, that they would bear any higher power with advantage. The edges appear deficient in straightness and sharpness, and this appearance is exaggerated by the numerous discolorations upon the silvered surface. The probable error of a single setting of a microscope appeared to be about double of that in the Washington circle, or 0″.2 to 0″.3 against 0″.10 to 0″.15. From these facts I am led to the conclusion that an improved system in the construction of circles is a desideratum.

It is true that the necessary probable error of astronomical observations arising from unavoidable disturbing causes is such that no great additional accuracy in single observations would be obtainable by a more accurate reading of the circle. The object of increased accuracy of reading is to facilitate the determination of errors of division. The latter must be determined with a precision corresponding, not merely to that of a single observation, but to the mean of a great number of observations. To do this without an enormous expenditure of labor, the microscopes must read with such precision that a single determination of each division will suffice. The greatest improvement in this direction would be made by the introduction of glass circles which have lately been proposed by several American physicists. The practicability of this innovation can, however, only be determined by experiment. Without pretending to decide, at present, whether glass or metal will prove to be the best material, I do feel that astronomers ought not to rest satisfied with a degree of accuracy so far behind that reached by the working physicists, who cut one or two thousand divisions to the millimeter, and space them so evenly that their inequalities defy direct measurement.

In the Strassburg circle an innovation has been made, designed to render unnecessary the determination of more than a limited number of division errors. One of the circles is divided only to every degree, and four of these degrees, distant 90 degrees from each other, are divided to every two minutes. Thus there are in all 480 divisions on the circle, and the errors of these can be determined with great precision without an inordinate expenditure of labor. With the circle thus divided an arc of any required length can be measured, one of whose termini shall lie in the degree which is finely divided, and the other on one of the entire degrees. To do this it is necessary to adjust the circle on the axis with each observation in such way that that observation shall be made upon the finely divided part, while the nadir or horizontal point shall fall upon an entire degree. The latter point must then be separately determined for each astronomical observation. I cannot think but that the labor of doing this exceeds the advantage gained by it.

MERCURY BASIN FOR NADIR POINT.

I found at Strassburg, Leyden, and other continental observatories, a plan of mercury basin which works so perfectly that I am surprised at its being almost unknown outside of Germany. At every observatory, in or near a great city, observations of the nadir point and of stars by reflection are rendered difficult by the tremors produced by wind, the passing of carriages, and the movement of men or animals in the neighborhood. Various ingenious and complicated contrivances are in use for avoiding this difficulty, none of which are entirely satisfactory. The use of a copper basin to hold the mercury was proposed in Germany early in the present century, but the conditions necessary to render such a basin successful seem never to have become well understood. In its most improved form the basin has no sides, but is simply a circular plate of metal, of which the upper surface, instead of being perfectly flat, is slightly concave, the figure of the concavity being spherical. The depth at the center is but a fraction of a millimeter. The surface is copper, or the whole basin may be made of copper, because in contact with this metal the mercury does not roll into globules, at least when amalgamated with it. In use the top of the basin is approximately leveled with a spirit-level. A little mercury is then poured upon it, and the surface of the mercury is gradually brushed off, partly to remove dust and impurities and partly in order to get rid of the surplus mercury. There is then left a layer of mercury in the center of the basin so thin that waves cannot continue on its surface. At Leyden, Professor Van de Sande Bakhuyzen gave me an opportunity to make very careful experiments on the working of this system. The sphericity of the basin guards against what has been considered one of the dangers in using an arrangement of this kind, namely, a possible minute inclination of the liquid surface arising from the cohesion between the mercury and the copper of the containing vessel. I found that in making an observation of the nadir point the heavy walking of men around the room produced no disturbance whatever, and even stamping on the floor in the neighborhood of the instrument only caused a momentary disappearance of the reflected image of the wires.

In the application of this form of basin it is desirable that the plate should be considerably larger than the objective in order that the layer of mercury may be equal to the latter and yet have plenty of margin around it on the plate.

METHODS OF DETERMINING FLEXURE, ETC.

In the use of a vertical circle of any sort, when the highest precision is aimed at, the determination of the effects produced by the bending of the instrument in the different positions has always been one of the most difficult problems.

The determination of the horizontal flexure is commonly considered to offer no difficulty. The familiar method of setting the opposing collimators in such a position that light can pass from one to the other through an opening in the central cube of the meridian circle, and then observing the horizontal wires in each of them with the circle, is of universal application. But even in the simplest case irregularities and discordances are frequently found. In the Washington circle I traced these discordances to the effect of refraction caused by the different temperatures of different strata of the air in the observing room and in the instrument. It is therefore absolutely necessary to success that the determination should be made when there is a perfect uniformity of temperature inside, around, and above the instrument. This was found practicable only in periods of long-continued rain, which cooled off the roof of the building and thus prevented an accumulation of warm air in the upper part of the room.

This method has generally been employed only when the instrument was horizontal, and its application in other positions is so troublesome that it has seldom been undertaken. At Paris, however, I found in use on the new Bischoffsheim circle a vertical collimator which, although apparently not intended for that purpose, could readily be used to determine the flexure in a vertical position. The collimator itself is supported in a horizontal position upon a standard on the east pier, around which it turns upon a vertical axis. When placed in position for use its objective is over the center of the telescope. To receive the rays from the latter a reflecting prism is placed in front of its objective. Thus the result is optically the same as if the collimator looked vertically down into the telescope of the main instrument. There would be no difficulty in setting the collimator either upon its reflected image in the basin of quicksilver below, or on another vertical telescope below the floor. The apparatus would then be available for the determination of flexure.

MR. LOEWY'S METHOD OF MEASURING FLEXURE.

An ingenious plan has recently been proposed by Mr. Loewy, vice-director of the Paris Observatory, for determining the flexure of the telescope in all positions. It has been so fully described in the *Comptes Rendus* and other publications that I need only here give its general principle.

A small glass instrument which combines the function of a lens and a reflector is placed in the central cube of the telescope. The flexures of the two ends of the telescope, relatively to the reflecting surface of this glass, are separately and independently determined in all positions of the instrument. It is assumed that the glass, being in the neutral axis of the telescope, the astronomical effect of the flexure will be given by the difference in the flexures of the two ends relatively to the glass. Ingenious and well considered as this method is, I cannot consider it reliable for determining the effects of flexure, because it leaves out of account the bending of the parts of the instrument between the central cube and the divisions on the circle. In the Washington circle there is a well-marked flexure of the circle itself, which may be expressed by saying that if the central cube revolves uniformly the circumference of the circle does not revolve uniformly but is affected with a periodic inequality. Hence, to make the determination free from all sources of error, the flexure must be determined by a direct comparison of the optical axis of the telescope with the reading of the circle divisions under the microscopes. This can be done only by pairs of opposing collimators on the usual or Besselian plan, or on some other plan by which rays can be sent in the same straight line in two opposite directions.

COLLIMATORS AND MERIDIAN MARKS.

The old-fashioned system of placing meridian marks at such a distance that they could be observed through the telescope of the transit circle without changing the astronomical focus may be regarded as now entirely abandoned, owing to the bad effect produced on the images by the passage of the light through several miles of air near the ground. The present system is to place the meridian mark at a distance of 100 or 200 yards and to render the rays emanating from it parallel by a lens of long focus. The plan of putting this lens as a cap over the objective has been abandoned, owing to its displacement of the optical center of the combined system of the lens and the object-glass. It is therefore usually fixed on top of a pier. But at Strassburg a different system is adopted. No lens of long focus is used at all, but the telescope is pointed directly upon the meridian mark and the rays are brought to a focus in the plane of the spider lines by means of a lens of short focus which can be slid into the eye-piece of the telescope. On this plan the position of the image will depend upon that of the small lens—a dependence which I think ought to be avoided. The best system seems to me to be that of the fixed objective of long focus.

At Strassburg the fixity of the meridian mark is assured by supporting it on a very firm stone foundation and protecting it by a frame building from the rays of the sun. The necessity of these precautions is too obvious to require any comment upon them.

At Paris a very ingenious system of reflecting collimators is applied to the great transit circle. As, however, this system was probably adopted only because there was no room for collimators of the usual construction, I did not deem it necessary to prepare a description of them. A system of fiducial lines which may be adopted with advantage in ordinary collimators is, however, worthy of note. Instead of setting one spider line upon the image of another, the spider line in one collimator is replaced by a fine transparent line through a narrow band of some opaque substance on a plate of glass. Thus when the observer looks at the image of this band in the other collimator he sees in the center of the field a fine horizontal or vertical bright line on which he can set the dark line of his collimator with great precision. This plan does not, however, so far as I can see, readily permit the setting to be made by means of the dark band collimator. Whether this limitation is a serious defect is a question on which opinions may differ.

OBSERVATORY BUILDINGS.

In the course of my journey I had the opportunity of visiting two new observatories of the first class erected within the past few years: one, the Imperial Observatory at Vienna, the other the Astro-Physical Observatory at Potsdam. It is generally necessary to design an observatory with especial reference to the character of the observations to be made and the objects to be pursued. To this may be added the frequent necessity for gratifying some public taste with respect to architecture. For these reasons one observatory cannot well serve as a model for another; but there are certain special features which would work equally well under nearly all conditions, and which are therefore worthy of consideration in building any observatory.

In the Vienna Observatory the architectural element predominates. I did not observe any new feature of especial importance to the designers of future observatories except those already noted.

The Potsdam Observatory, as its name implies, was designed with especial reference to physical observations upon the heavenly bodies. This branch of astronomy in its present development is so new that every establishment for prosecuting it has to be planned with reference to the special work to be done. Hence, notwithstanding that the observatory in question is, in its outfit and design, one of the most perfect yet built, those features of it which it would be advisable to incorporate in another establishment, built perhaps for another purpose, would generally occur to the designers of such an establishment. The following are, however, well worthy of consideration in all plans of new observatories.

The effect of the sun's rays upon the metal roof of the building is to heat the air in immediate contact with the roof and thus to injure the definition of the heavenly body seen from within the observing rooms in the daytime. To avoid this difficulty the roof is covered with soil and sodded with green turf and thus kept as cool as the surrounding air, how hot soever the sun's rays may be. It is of course necessary to keep the turf watered. Possibly any other absorbent substance might answer the purpose of the turf, but the latter has at least the advantage of cheapness.

It is a common feature of all, or nearly all the continental observatories, that quarters are provided for the astronomers, generally in the building itself. This offers the great advantage that the astronomers are nearly always near their instruments, and may be regarded as absolutely essential to the efficiency of any large observatory, especially if it is not in the midst of a city. At Potsdam the houses of some of the astronomers are separated from the building, but the general rule is that the building accommodates the director and such of the assistants as are engaged in actual observations, together with their families. This collection of several families in the same building is more accordant with European habits than with our own, and the question of its introduction among us can be settled only by careful consideration. I can only say that I noticed no serious inconvenience arising from it.

CLOCKS.

In most astronomical work of the first class, especially in meridian observations, the perfection of the clock is as necessary as that of any other instrument. But it seems to be an observed fact that no certain way has yet been found of securing an approach to perfection in the rate of the clock. All we can say is, that clocks of marvelous excellence are now and then made, sometimes by one maker and sometimes by another, and that of these clocks some are permanently good while others, in the course of time, deteriorate. I found a few examples of clocks preserving their rate with remarkable uniformity through considerable periods. One of these is the Normal clock of the Berlin Observatory, made by Tiede. It is inclosed in an air-tight case in order to prevent changes of rate arising from variations in the barometric pressure. The temperature compensation is unfortunately imperfect, so that the rate is subject to an annual change. This fact has prevented the exact discussion to which I desired to subject it. It would seem, however, from a cursory examination, the materials for which were courteously afforded me by Professor Förster, that the annual change from temperature does not exceed 10 or 15 seconds per year, and that when this is allowed for the differences between the actual and the computed errors will be a very few seconds per year. In recent times the clocks furnished by Howhü, of Amsterdam, have secured a reputation for uniform excellence which has never been surpassed; that is, instead of being able to occasionally turn out a clock of remarkable excellence, all the clocks of this artist, so far as they have been discussed, are of the first class.

The following exhibit of the observed and computed errors of one of his clocks through a period of nearly two years has been selected, not from a belief that this particular clock was better than others, but because the data for the examination were at hand:

Comparison of the observed and computed corrections of Clock Howhü 2:, at the observatory of Leyden, 1865, *December* 1, to 1867, *October* 25.

[FORMULA FOR COMPUTED DAILY RATE: $+0^s.750 - 0^s.03642\,(T - 14°) + 0^s.0106\,(B - 760^{mm})$.
T = temperature, cent.:
B = height of barometer.]

	Correction.		
	Observed.	Computed.	Difference.
1865.	s.	s.	s.
Dec. 1	20.9	20.9	0.0
29	56.3	54.8	+ 1.5
1866.			
Jan. 26	89.1	84.2	+ 4.9
Feb. 23	119.8	112.1	+ 7.7
Mar. 30	261.1	148.0	+13.1
Apr. 27	188.9	172.5	+16.4
May 25	215.3	195.5	+19.8
June 29	236.5	216.0	+20.5
July 27	249.7	231.7	+18.0
Aug. 31	265.0	252.3	+12.7
Sept. 28	277.9	270.0	+ 7.9
Oct. 26	297.4	293.4	+ 4.0
Nov. 30	327.8	326.5	+ 1.3
Dec. 28	356.9	355.9	+ 1.0
1867.			
Jan. 25	385.2	386.5	− 1.3
Feb. 22	414.3	416.1	− 1.8
Mar. 29	452.2	454.5	− 2.3
Apr. 26	476.1	479.1	− 3.0
May 31	505.8	505.3	+ 0.5
June 28	524.7	522.9	+ 1.8
July 26	540.8	539.4	+ 1.4
Aug. 30	559.9	559.5	+ 0.4
Sept. 27	575.4	577.2	− 1.8
Oct. 25	594.6	600.6	− 6.0

In this connection I may be allowed to call attention to the unsatisfactory character of the data usually presented for estimating the excellence of clocks. In my judgment the estimate of the clock should be founded upon its errors, determined from time to time through a period of not less than a year. These errors should be exhibited in connection with the mean temperature of the clock-room, and if the clock is not in an air-tight case the height of the barometer should also be given. A calculated error should then be carried through the whole period, in which the corrections for temperature and height of the barometer should be introduced. A clock which stands this test well may be presumed beyond doubt to keep its rate during short intervals, which is generally the important point.

It is very common to present as sufficient data for judging of a clock an exhibit of its daily rates from time to time. If these rates were really determined with the last degree of accuracy they might be sufficient for the purpose. But as found in practice they will be the result, not merely of the actual rates of the clock, but of various personal differences among the observers and changes in the pointing of the instrument as well as the accidental errors of observation. From these causes, although the clock were perfect, we might expect an apparent difference of several hundredths of a second between its apparent rate on successive days.

The barometric change in the rates of all clocks of the usual construction is so important a drawback that it should no longer be tolerated in work of the first class. Two methods have been proposed: the one, that already mentioned, of inclosing the clock in an air-tight case; the other, to supply it with a barometric compensation. The latter method is undoubtedly the easiest, but where the necessary perfection of arrangements can be secured the former must be considered greatly preferable. The grounds of preference are that the air can be exhausted from the case to any extent, thus diminishing its resistance to the motion of the pendulum and permitting a diminution in the driving power. Again, if, instead of air, the case be filled with some gas which does not act on the oil, the slow oxidation of the latter may be prevented. It may therefore be expected that under this system a clock could be allowed to remain undisturbed for a longer period than under any other.

Very respectfully, your obedient servant,

SIMON NEWCOMB,
Professor, United States Navy.

Hon. W. E. CHANDLER,
Secretary of the Navy.

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